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Compact Superconducting Ring at Ritsumeikan University

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A compact superconducting storage ring (0.575 GeV and 300 mA) with a racetrack microtron injection system was installed at Ritsumeikan University and has been operated successfully since April 1996. As the radius of the circular electron orbit is small (0.5 m), it is possible to use a radiation beam of relatively high photon flux at a short distance from the source point. Beamlines have been constructed including those for XAFS, soft X-ray spectroscopy, VUV spectroscopy, fluorescent X-ray analysis, soft X-ray microscopy, X-ray diffraction/scattering and photoelectron spectroscopy; the photoelectron spectrometer is combined with an ion-beam-scattering spectrometer to obtain information both on the electronic states and on the atomic arrangements of a solid surface. In addition there are two beamlines, one for LIGA exposure and the other for synchrotron radiation ablation, which are devoted to producing new devices and materials. The synchrotron radiation facility is open not only to users in the University but also to researchers in industry, governmental institutions and other universities.

Keywords: compact superconducting ring; Ritsumeikan University.

1. Introduction

Synchrotron radiation has become one of the most powerful tools in science and engineering and without its full utilization it will not be possible to explore new frontiers in the 21st century. There is an increasing demand for new radiation sources all over the world and various efforts are being made to construct electron storage rings. In Japan there are several active storage rings such as those at the Photon Factory, Institute for Molecular Science *etc.*, but they are national facilities for common use by all researchers in the country and beam time for synchrotron radiation experiments has to be shared by a number of groups.

Ritsumeikan University decided in 1993 to start a project to establish its own synchrotron radiation facility on the University campus. The aim of the project is to install a compact storage ring which allows easy user access, enabling professors and students to perform innovative research using synchrotron radiation and promoting extensive cooperation between the University researchers and industry.

The compact superconducting storage ring AURORA was chosen to be installed. It is designed and manufactured by Sumitomo Heavy Industries and has been described elsewhere (Takahashi, 1987; Yamada *et al.*, 1989). After minor modification of the original design, the ring was installed in the Synchrotron Radiation Center at the Biwako-Kusatsu campus, Shiga Prefecture, in April 1996, and has been operated successfully since then. Nine beamlines have been constructed to meet user requirements, taking into account the ring characteristics.

This paper describes the present status of the radiation source and beamlines.

2. Radiation source

The injector is a racetrack-type microtron which provides an electron beam of 1 mA at an energy of 150 MeV to the storage ring at a repetition rate of 10 Hz. A half-integer resonance injection method is adopted (Takayama, 1987).

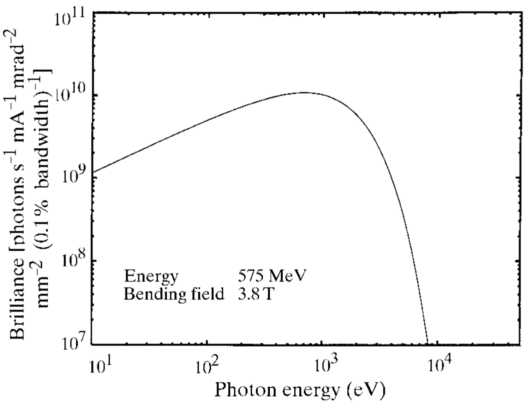

Figure 1
The spectrum of radiation from the AURORA compact superconducting ring.

Table 1
Parameters of the injector and storage ring.

Injector parameters

Energy	150 MeV
Repetition	10 Hz
Peak current	1 mA
Pulse width	2 μs

Storage ring parameters

Energy	575 MeV
Stored current	300 mA
Circumference	3.14 m
Radius of curvature	0.5 m
Field strength	3.8 T
RF frequency	190.86 MHz
Number of cavities	1
Harmonic number	2
Critical energy of radiation	844 eV
Vertical beam size	0.14 mm
Horizontal beam size	1.3 mm
Beam lifetime	300 min (July 1997)

On average, an electron beam of 300 mA can be accumulated in 20 min.

The ring is composed of a single superconducting magnet, in which the electron orbit is exactly circular with a radius of 0.5 m. The energy of the accumulated electron beam is boosted to 575 MeV synchronously with an increase in the field strength of the magnet; the ring is normally operated at this energy, the initial beam current being 300 mA. The lifetime of the stored electron beam depends on the vacuum condition of the ring; the lifetime had been 200 min for the past few months but has recently increased to 300 min. The injection and boosting operations are fully automatic.

The energy spectrum of the radiation emitted from the ring is shown in Fig. 1. The brilliance is not particularly high, but the small radius of the electron orbit in the strong magnetic field of 3.8 T enables the radiation to be used at a distance so close to the source point that the beam has a relatively high photon flux. The critical energy of the radiation is 844 eV, higher than that of other rings of approximately the same beam energy, and the radiation contains an X-ray component, although it is not intense. There is no beam-focusing system in the ring, but the cross-sectional size of the radiation beam is small, 0.14 mm (vertical) by 1.3 mm (horizontal). Very recently, more precise measurements have been made using an interference method and it has been shown that the vertical beam size can be lowered to as little as 0.017 mm (Mitsuhashi *et al.*, 1997). The simple structure of the ring gives rise to stability in the beam position.

Table 1 lists the parameters of the injector and the ring.

3. Beamlines

There are 16 radiation-beam extraction ports in the ring, of which (in mid-1997) nine are occupied by beamlines for synchrotron radiation experiments and two are used for beam monitoring. Fig. 2 shows the arrangement of the beamlines in the experimental hall, with the ring in the centre.

In view of the photon energy range available, most of the beamlines have been designed to use the soft X-ray and VUV components of the radiation. In addition, there are three beamlines which utilize the X-ray component. Taking advantage of the small radius of the ring, the optical components of the beamlines are placed at distances ranging from 2 to 4 m. The beamlines are listed in Table 2 . Descriptions of three of them follow, while the others are described in the *RITS Synchrotron Radiation Center Activity Report* (RITS Synchrotron Radiation Center, 1997).

Recent development of the LIGA technique has opened up a method by which components of micro-electro-mechanical systems can be manufactured using synchrotron radiation. Beamline BL-6 has been constructed for

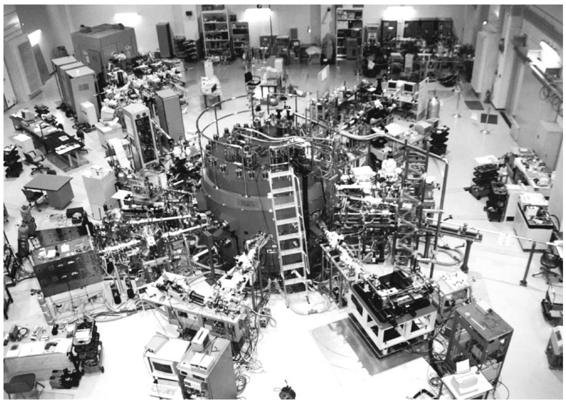

Figure 2
Photograph showing the arrangement of beamlines in the experimental hall.

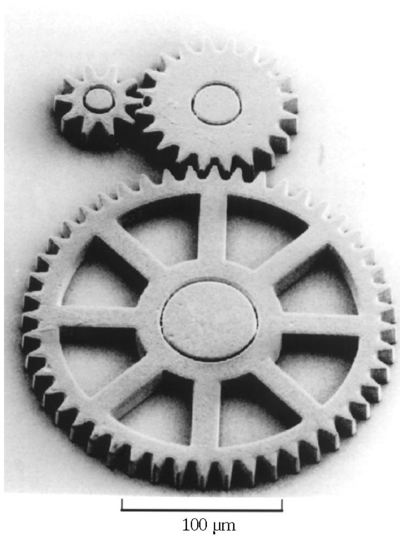

Figure 3
50 μm-high microgears obtained using a tungsten absorber with a silicon nitride membrane.

Table 2
List of beamlines.

Beamline	Use	Optical components	Energy range (eV)	$\Delta E/E$
BL-1	Soft X-ray spectroscopy	Cylindrically bent mirror, bent crystal monochromator	2040–2850 (Ge), 1250–1760 (ADP)	$3.2–4.3 \times 10^{-4}$
BL-2	VUV spectroscopy	Cylindrically bent mirror, bent grazing-incidence grating	50–600	1.3×10^{-3}
BL-3	X-ray diffraction	Double-crystal monochromator (Si 111, Si 220)	4000–8000	2×10^{-4}
BL-4	XAFS	Double-crystal monochromator (Si 220)	3400–10000	1×10^{-4}
BL-6	LIGA exposure	–	2000–10000	–
BL-8	Photoelectron spectroscopy (ion-beam scattering)	Pre-focusing cylindrically bent mirror, plane mirror, varied-space plane grating, post-focusing toroidal mirror (toroidal electrostatic analyser)	5–700	$2.0–6.7 \times 10^{-4}$
BL-12	Soft X-ray microscopy	Plane mirror, condenser and objective zone plates	280–540	–
BL-13	Fluorescent X-ray analysis	–	3000–10000	–
BL-14	Synchrotron radiation ablation	Cylindrically bent mirror	50–2000	–

LIGA exposure. A radiation beam 5 mm (vertical) by 30 mm (horizontal) passes through beryllium and kapton windows into an exposure chamber, in which a mask–wafer system is mounted on the *XY* stage. During exposure the chamber is filled with helium gas. In addition to the exposure system, an electron-beam writer for preparing masks and equipment for electroforming and moulding have been installed in a building near the Synchrotron Radiation Center and thus it is possible to perform serial processing of micromachining on the University campus. This is the first university LIGA facility in the country. Extended cooperation with researchers in industrial corporations is in progress. Fig. 3 shows 50 μm-high microgears obtained using a tungsten absorber with a silicon nitride membrane. Details are given by Sugiyama *et al.* (1996).

Photoelectron spectroscopy provides information on the electronic structure of materials and is indispensable in the development of semiconductor technology. It is also desirable to be able to obtain information on the atomic arrangement of the sample material. At BL-8 a combined system of a photoelectron spectrometer and an ion-beam-scattering spectrometer was constucted. The former consists of a pre-focusing cylindrically bent mirror, a plane mirror, a varied-line-space plane-grating monochromator, a post-focusing toroidal mirror and a photoelectron energy analyser. The latter consists of an ion (H^+, He^+ and Ne^+) accelerator and an ion-beam-scattering chamber with a toroidal electrostatic energy analyser. The sample can be transported in vacuum from the photoelectron chamber to the ion-beam chamber and *vice versa*. The system is named SORIS (synchrotron radiation coupled with ion-beam scattering) and a detailed description of the structure and performance of the beamline is given by Kido *et al.* (1997). Fig. 4 shows a photograph of SORIS, in which the electron energy analyser and the sample-transporting device can be seen.

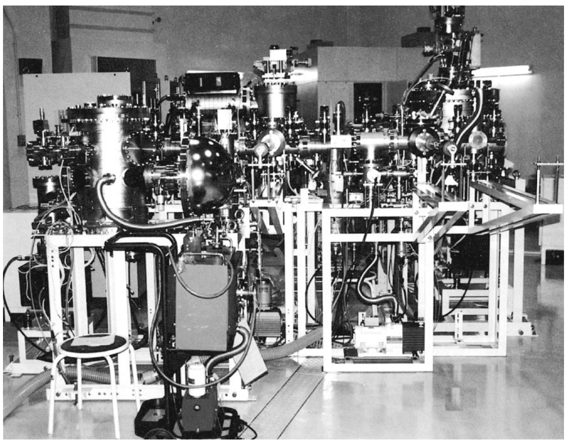

Figure 4
Photograph of the combined photoelectron spectroscopy and ion-beam-scattering spectroscopy (SORIS) system at BL-8.

Taking advantage of the relatively high critical energy of the radiation, a beamline has been constructed at BL-3 where X-ray diffraction and/or scattering experiments can be performed. It has been shown that radiation in the energy range 5–8 keV is useful for measurement of the intensities of Bragg reflections and is particularly suitable for structural studies involving anomalous-scattering phenomena with crystals containing 3*d* metal atoms (Iwasaki *et al.*, 1998).

4. Synchrotron Radiation Center as a facility for student research and education

Ritsumeikan University has established a new Photonics Department in the Faculty of Science and Engineering, in which both undergraduate and graduate students learn about the activities of the Synchrotron Radiation Center and pursue research on the application of radiation to material and biological sciences and on beamline instrumentation. As the Center is located on the University campus, they can visit frequently and easily obtain beamtime for experiments. Their experience at the Center contributes towards their becoming experts in synchrotron radiation science and technology and related fields.

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